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by M J Dutton

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Variability in space and time of the 30-second average wind at the surface and its relevance to the siting of multiple anemometers at airfields

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Introduction and background

An airfield's anemometer is normally sited in such a position as to give a wind as 'representative' as possible of the entire airfield, or at least that portion of the airfield covered by runways. The mean wind, averaged over at least ten minutes, and the standard deviation of short period values about this mean (i.e. the variability or gustiness), at the most critical points on the airfield, namely the touch-down and take-off areas, should not normally deviate systematically from those at the anemometer site. However, even if this is true for the 10-minute mean wind, when the wavelengths of wind disturbances (or turbulent components of the wind) are significantly less than the horizontal dimensions of the airfield, differences between these turbulent components at two points separated by, for example, the length of a runway are an inevitable consequence of the natural variability of the surface winds on these short time or length scales, even in steady-state conditions (i.e. when the mean wind and gustiness are constant in time). The passages of mesoscale and synoptic-scale features, such as gust-fronts, squall-lines and major frontal systems, introduce significant 'discontinuities' which add to the problem.

At the large majority of airfields, a single anemometer is used, sometimes sited centrally but often as close as practically possible to one of the touch-down or take-off positions. In attempting to determine the usefulness of installing a second anemometer at the opposite end of the runway (to be used when the touch-down or take-off point is at that end), or indeed near the ends of all operational runways, we need to know, at least roughly, how often differences of various magnitudes between simultaneous short-period (e.g. 30-second) winds at the two ends of the runway occur, and how these figures compare with those for two winds measured at one point but separated in time by the operationally

realistic time interval (or lag) between the wind measurement and its use by the pilot at take-off or touch-down. This time-lag is typically about one minute. This latter set of figures, for time-lag of about a minute, would in practice be the best achievable, or most optimistic, since the assumption is made that an anemometer is always sited directly at the touch-down/take-off point and the only difference or error would be that due solely to the time-lag, no spatial separation being involved. Ideally, for an analysis of this type, synchronous short-period wind data from two sites, separated by about 3 km, over a period of at least a year is required; no such data exist, however, and this note presents the results of an analysis designed to estimate, using 30-sec wind data at a single site, the frequency distribution of differences between simultaneous 30-sec wind averages at two points separated by about 3 km; the method used necessarily assumes Taylor's Hypothesis of 'frozen' turbulence, which effectively states that the turbulence time-series sensed at a fixed point can be regarded, subject to certain limitations, as equivalent to a 'frozen' spatial turbulence field being advected past the fixed point by the long-period (e.g. 5-minute) mean wind, $\underline{\bar{V}}$. In this way, the characteristic wavelength, λ, of a t-second turbulent component can be equated to $\bar{V}t$ (where $\bar{V} = |\underline{\bar{V}}|$); note that t is the fixed-point averaging period. This concept, that turbulent eddies are embedded in, and carried along with, the mean wind, has been shown to give a good approximation to the actual air-flow over short distances ($<$100m) in a variety of situations (see, for example, Harold and Browning, 1968; Shiotani 1969; Pielke and Panofsky, 1970; Powell and Elderkin, 1974; Shiotani and Iwatani, 1976); gusts and lulls created by the frictional effects of topography, or evolving through dynamic processes, apparently change relatively slowly, and, in general, the larger their size the more slowly they change. Such a concept does, however, have its limitations in the real atmosphere, and it is undoubtedly stretched beyond its strict theoretical limits for horizontal

separations as large as 2-4 km; in any single situation the theoretical two-point wind differences derived using this hypothesis will not correspond well with the actual differences. But, for the purposes of constructing an estimated statistical distribution of the wind differences over a wide range of situations and over a long period of time, the hypothesis is believed to provide an adequate basis.

For aircraft taking off or landing roughly into the mean wind direction, the 30-second run of wind past a fixed anemometer will usually be equivalent to the distance covered by an aircraft in a few seconds of flight, and therefore probably represents about the minimum size of eddy which might significantly affect the aircraft's flight path (Hardy, 1974).

Also presented in this note are statistics of differences between two 30-second winds at the same point but separated by various time-lags.

By comparing 30-second winds in the ways described, the assumption is implied that the wind supplied to the pilot is always the most recent 30-second average. It should be borne in mind that, despite numerous recommendations over the past ten years (e.g. ICAO, 1967 and 1974; Sparks and Keddie, 1971; Hardy 1974; Dutton 1975 and 1976) for the use, in this context, of an averaging period in the range 30-seconds to 5 minutes (depending on what magnitude of wind error is required to be minimised), the use of 'spot' values, or at best 5-to 10-second values, is apparently still widespread. The variability of such a short-period mean, both in space and time, is such that, as a forecast of the 30-second wind a minute or two later, even directly at the anemometer site, it will almost always prove inferior to a wind averaged over 30 sec - 5 minutes.

The data for analysis

Series of 30-second surface (10m) winds, with wind direction recorded to the nearest degree and wind speed to the nearest 0.1 knot, recorded by a Meteorological Office Mk 5 wind system (Else 1974), with a DALE (Digital Anemograph Logging Equipment) unit attached

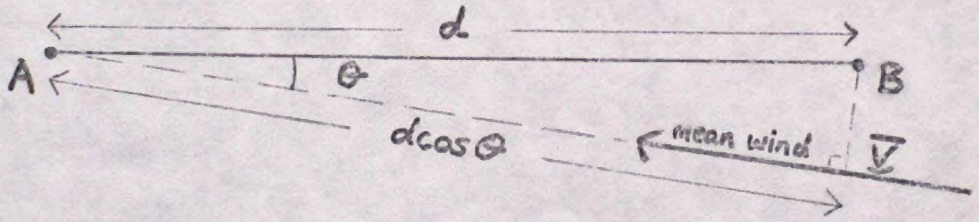
(Burtonshaw and Munro, 1977), and operating at Heathrow (south-west site) from January to December 1974, provide the necessary data for this analysis.

Due to occasional inoperative periods or corrupt data, the record is somewhat fragmented; the actual periods available for analysis are listed in the Appendix to this note. They total 7298 hours (304 days and 2 hours), 83 per cent of the maximum possible (365 days), and are such that the data-set can be safely considered to be unbiased from a meteorological point of view.

Analysis

(a) Spatial wind variation

Consider the 30-second winds at two points, A and B, separated by distance d, when the mean wind (averaged over a relatively long period compared to 30 seconds) is directed at a small angle, θ, to the line AB (figure 1).



$\underset{\sim}{\bar{V}}$ is the mean wind. $\bar{V} = |\underset{\sim}{\bar{V}}|$

If $\underset{\sim}{V}_A(t)$, $\underset{\sim}{V}_B(t)$ are, respectively, the 30-sec winds at A and B centred at time t, then, applying Taylor's 'frozen' turbulence concept

$$\underset{\sim}{V}_A(t) = \underset{\sim}{V}_B(t-\Delta t) \qquad (1)$$

where $$\Delta t = \bar{V}^{-1} d\cos\theta \quad (\approx \bar{V}^{-1} d \text{ for small } \theta) \qquad (2)$$

Now
$$\underset{\sim}{\Delta V}_{AB}(t) = \underset{\sim}{V}_B(t) - \underset{\sim}{V}_A(t)$$
$$= \underset{\sim}{V}_B(t) - \underset{\sim}{V}_B(t-\Delta t) \qquad (3)$$

Since we are dealing with a time-series of discrete non-overlapping 30-second winds we should rewrite this as:

$$\underset{\sim}{\Delta V}_{AB}(n) = \underset{\sim}{V}_B(n) - \underset{\sim}{V}_B(n-\Delta n) \qquad (4)$$

$\underset{\sim}{V_B}(n)$ is the nth 30-second wind in the series and

$\Delta n = \Delta t/30$ rounded to the nearest integer (5)

(i.e. Δn = 0, 1, 2, 3 .....)

In situations where a substantial cross-runway wind component exists, Taylor's hypothesis does not help us. However, what we can reasonably assume is that, in the large majority of situations there is negligible correlation between 30-second winds at two points separated in the cross-wind direction by a distance significantly larger than $\lambda = \bar{V}t = 30\bar{V}$, the characteristic wavelength of the 30-sec wind (Giblett, 1932). In view of this, we can adopt an almost identical procedure to that described above (for wind direction roughly along AB), with the proviso that a minimum value for Δn, Δn_{min}, is introduced; this ensures that, in cross-wind situations, the correlation between 30-sec winds at A and B is never greater than that (autocorrelation) between two 30-sec winds at B separated in time by Δn_{min} time-steps. For Δn_{min} = 5 ($2\frac{1}{2}$ minutes) the autocorrelation is sufficiently low for the derived frequency distribution of differences between 30-sec winds at A and B to be reasonably realistic for our purposes.

A computer program (in FORTRAN, reference name MØ9MANEM) has been written to access the DALE 30-sec wind data and produce frequency distributions of $|\Delta \underset{\sim}{V}_{AB}|$ within pre-set ranges 0-2, 2-4, 4-6.....18-20, $\geq$ 20 knots, as a function of the 5-minute mean wind speed; mean and root-mean-square (rms) values of $|\Delta \underset{\sim}{V}_{AB}|$ are also computed. The averaging period used to calculate the 'advecting' vector mean wind is also 5 minutes; for differences computed at the nth time step the mean wind is the vector average of :-

$\underset{\sim}{V_B}(n-5)$, $\underset{\sim}{V_B}(n-4)$ ..... $\underset{\sim}{V_B}(n)$ ..... $\underset{\sim}{V_B}(n+4)$.

Point B is assumed to be sited directly east of point A , and the distance d is taken to be a typical runway length, 3000 metres. Differences were computed at every forth time step throughout the time series of winds. For computational

convenience Δn is limited to a maximum of 39 (19½ minutes); a minimum value for Δn has already been mentioned ($\Delta n_{min} = 5, \Delta n_{max} = 39$). This program was also run putting d = 2000m, for comparison.

It is also interesting to examine the distribution of differences arrived at using the same method except that $\Delta t = \bar{V}^{-1} d$, rather than $\Delta t = \bar{V}^{-1} d\cos\theta$. This would not greatly affect the results for situations when the mean wind direction is within about 30 degrees of the line AB, but has the effect, in situations when a substantial crosswind exists, of increasing the equivalent time-lag (Δt), since $\bar{V}^{-1} d > \bar{V}^{-1} d\cos\theta$ in these circumstances; in addition Δn is always (for the data-set analysed in this note) greater than the imposed minimum value of 5. The basic program was therefore also run with $\Delta t = \bar{V}^{-1} d$.

In the author's opinion the results of the analysis with $\Delta t = \bar{V}^{-1} d\cos\theta$ are probably a little optimistic (ie there may be more large differences than indicated), whereas the results for $\Delta t = \bar{V}^{-1} d$ are considered to be rather pessimistic. The true figures probably lie somewhere in-between, and probably closer to those for $\Delta t = \bar{V}^{-1} d\cos\theta$.

(b) Temporal Wind Variation (at a fixed point)

Define $\underset{\sim}{\Delta V}_{\delta t}(t)$ as the vector difference between the wind at time t and that at time t-δt (both winds measured at the same point) i.e.

$$\underset{\sim}{\Delta V}_{\delta t}(t) = \underset{\sim}{V}(t) - \underset{\sim}{V}(t-\delta t) \qquad (6)$$

or, if we are dealing with a series of discrete 30-second values

$$\underset{\sim}{\Delta V}_{\delta n}(n) = \underset{\sim}{V}(n) - \underset{\sim}{V}(n-\delta n) \qquad (7)$$

where $\delta n = \delta t / 30$ rounded to the nearest integer (8)

The same computer program (MØMANEM) was slightly modified (by arranging for a pre-set constant value of Δn) to produce frequency distributions of the scalar quantity $|\underset{\sim}{\Delta V}_{\delta t}|$ within various ranges (as in the analysis on spatial variations), using the same series of DALE 30-sec winds, for δn = 1,2,3,4,5,10,20,

30 and 40 (time-lags varying from ½ minute to 20 minutes). Results for δn greater than about 5 (2½ minutes) are not particularly relevant in the context of this note, but are included for interest.

As mentioned in the Introduction the $\delta n = 2$ (or 3) case gives an idea of the best achievable figures, since this is representative of the situation in which:-

(i) The anemometer is sited directly at the touch-down or take-off point.

(ii) The time interval between the measurement of the wind and its use by the pilot is about one minute.

In practice, of course, the anemometer cannot be sited nearer than about 200m away from the runway centre-line (measured perpendicular to that line). Recognizing the small amount of (spatial) variability associated with this 200m separation, it is probably more appropriate to take $\delta n = 3$, rather than $\delta n = 2$, as the case which gives the realistically best-achievable (most optimistic) exceedance statistics.

Results

(a) Spatial wind variation

Table 1 shows the percentage frequencies of vector difference magnitudes, $|\Delta \underset{\sim}{V}_{AB}|$, exceeding various thresholds up to 20 knots, for the year as a whole; actual numbers of exceedances are given in parentheses. These results are classified by mean (5-minute) wind speed, and the mean and rms values for $|\Delta \underset{\sim}{V}_{AB}|$ are also listed.

Over the year as a whole, differences exceeding 10kt and 14kt occurred 0.212 per cent (1 in 470) and 0.026 per cent (1 in 3800) of the time, and it can be seen that, as expected, the conditional probability of such events increases with increasing mean wind speed, due to the associated increasing level of turbulence (on the 30-second time-scale).

Tables 2 and 3 show the distribution for 'summer' months (May-October) and 'winter' months (November, December and January - April) respectively.

During 'summer' months differences exceeding 10kt and 14kt occurred 0.254 percent (1 in 400) and 0.035 percent (1 in 2900) of the time, compared with the equivalent 'winter' frequencies of 0.168 percent (1 in 600) and 0.017 percent (1 in 5900). Note that for thresholds above 12kt the 'summer' frequencies (for all wind speeds) are about double the equivalent 'winter' frequencies; this is almost certainly attributable to the higher frequency of purely convective phenomena during the summer at Heathrow (eg heavy showers, thunderstorms, line squalls). During the 'summer' months it is interesting to note that 82 percent (31 out of 38) of differences in excess of 14 knots occurred when the mean wind speed was less than 15 knots.

Figure 1 presents the 'ALL YEAR' results in graphical form. The exceedance probability (P), on a logarithmic scale, is plotted as a function of the threshold value (in knots) of $|\Delta \underset{\sim}{V}_{AB}|$ for:-

case (i) d = 3000m

case (ii) d = 2000m

case (iii) d = 3000m, with $\Delta t = \bar{V}^{-1} d$ (instead of $\Delta t = \bar{V}^{-1} d \cos\theta$)

Note that, for any given threshold value, the exceedance probabilities are of the same order of magnitude in all three cases; the case (iii) probabilities deviate from those for case (i) by, at most, a factor of 1.44 (at the 16-knot threshold).

(b) Temporal wind variation (at a fixed point)

Table 4 shows the percentage frequencies of vector difference magnitudes, $|\Delta \underset{\sim}{V}_{\delta n}|$, exceeding various thresholds up to 20kt, for the year as a whole, as functions of δn in the range 1 to 40 ($\delta t = \frac{1}{2}$ min to 20 min); actual numbers of exceedances are given in parentheses. These results are presented graphically in Figure 2 in which the exceedance probability (P), on a logarithmic scale, is plotted as a function of the threshold value (in knots) of $|\Delta \underset{\sim}{V}_{\delta t}|$ for each δt .

The exceedance probabilities for two-point (spatial) differences from

Table 1 (All wind speeds) are plotted here on Figure 2 for comparison; also plotted are results derived by the two-point difference program with d=2000 metres. Note that these exceedance probabilities correspond roughly to those for $|\Delta V_{\delta t}|$ for δt = 5 min.

For the operationally interesting case of δn =3, referred to earlier, differences of 10 kt and 14 kt occur 0.078 per cent (1 in 1300) and 0.009 percent (1 in 11000) of the time.

Brief discussion

It is important to bear in mind that the operationally 'best achievable' figures ($|\Delta V_{\delta n}|$ figures for δn =3, in Table 4) will only apply for that proportion of the time that aircraft touch-down or take-off close to (within 200 or 300 metres) an anemometer site. If there are anemometers at both ends of every runway, the δn =3 figures in Table 4 will always apply. If however the touch down or take-off point is close to the anemometer site on only a fraction of occasions, as is usually the case, the δn =3 figures will apply for that fraction of the time, while the (less favourable) distribution of two-point differences (for d $\approx$ 2-4 km) may well apply for the rest of the time. So, for a given airfield, the distribution of differences between a 30-second wind passed to the pilot (about one minute before touch-down or take-off) and the wind he actually experiences there (ie the error in the wind) obviously depends on the siting of the anemometer(s) and the operational runway-usage procedures at that airfield. For example, consider an airfield which has two runways and two anemometers: if these anemometers are sited such that 50 percent of all touch-downs and take-offs are near an anemometer, and the rest are about 2-4 km distant from an anemometer, then the best estimates of exceedance probabilities for various error thresholds would correspond to a 1:1 combination of the probabilities for

(i) $|\Delta V_{\delta n}|$ for δn=3 (Table 4)

and (ii) $|\Delta V_{AS}|$ for d =3 km (Table 1)

The effect of an additional anemometer, so that, perhaps, as much as 75 percent of all touch-downs/take-offs are near an anemometer, can also easily be assessed; in that event the probabilities for $|\Delta V_{\delta n}|$ for δn =3 would apply for 75 percent of the time. Table 5 lists best estimates of the exceedance probabilities for various error thresholds for various values of F, the percentage of all touch-downs and take-offs that occur close to an anemometer. F=0 corresponds to the worst case, in which the anemometer is 2-4 km from all touch-down/take-off points, while F=100 is the most favourable set-up for reducing the errors, an anemometer being sited close to all touch-down/take-off points.

The figures in parentheses in Table 5 are the ratios (percentage frequency) ÷ (percentage frequency for F=100) and serve to illustrate the degradation suffered relative to the F=100 percent case. For instance they show that errors in excess of 10, 14 and 20 kt occur about 2 to 3 times as often for F=25 percent than for F=100 percent (precise factors are 2.29, 2.47 and 3.00). The point has previously been raised that the frequencies of large two-point differences (figures for F=0) tend to be a little underestimated using the basic method described in this note (case (i) with $\Delta t = \bar{V}^{-1} d \cos\theta$); these F=0 frequencies therefore probably represent lower limits for our estimates. The two-point difference distributions for case (iii) (d=3000m, $\Delta t = \bar{V}^{-1} d$), presented in figure 1 and described earlier as being rather pessimistic, indicate that the upper limits for the estimated exceedance probabilities may be a factor of 1.5 greater than the lower limits. So the true probabilites for the F=0 case in table 5 may be a little higher than indicated, but not by more than about 50 percent. Table 5 leads us to conclude, therefore, that the frequency of errors in the 30-second wind passed to the pilot, about a minute before touch-down or take-off, in excess of, say, 14 knots or 20 knots can be reduced by a factor of 3 to 4 by changing from F=25 percent to F=100 percent, or by a factor of 2½ to 3 by changing from F=50 percent to F=100 percent.

Concluding Remarks

It should be stressed that the statistics of two-point differences quoted in this note are not derived using wind information from two anemometers. This note merely suggests a possible method of constructing an estimated statistical distribution of two-point differences using short-period winds recorded at a single site, by applying the concept of 'frozen turbulence'.

Obviously the best way to verify these estimates is to analyse short-period wind data from two accurately synchronous anemometer records, the anemometers being separated by a distance of 2-3 km. This is a virtually impossible task using conventional anemograph traces because of the poor time resolution and inadequate methods of synchronisation. If DALE units, recording accurately synchronous 30-second winds, could be attached to the two Heathrow anemometers for a period of at least three months (covering a reasonably wide range of meteorological situations), the distribution of actual measured two-point differences could be compared with the distribution arrived at by applying the method described in this note to one of the two anemometer records.

It should also be pointed out that all the statistics given in this note relate specifically to Heathrow; statistics for other sites with markedly different exposure and/or synoptic experience to Heathrow may be significantly different.

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TABLE 1 - PERCENTAGE FREQUENCIES OF VECTOR DIFFERENCES, $|\Delta V_{AB}|$, EXCEEDING VARIOUS THRESHOLDS (ALL YEAR)

Mean Wind Speed (kt)	Percentages of Vector Differences (knots) exceeding:- 2	4	6	8	10	12	14	16	18	20	Total (N)	Mean (kt)	r.m.s. (kt)
0-5	19.91	3.29	0.79	0.18	0.034	0.022	0.014	0.010	0.002	-	49990	1.315	1.753
	(9952)	(1646)	(394)	(90)	(17)	(11)	(7)	(5)	(1)				
5-10	37.72	7.69	1.69	0.40	0.123	0.044	0.017	0.008	0.004	-	92925	1.910	2.370
	(35055)	(7150)	(1572)	(375)	(114)	(41)	(16)	(7)	(4)				
10-15	60.27	18.90	4.42	0.99	0.236	0.070	0.032	0.018	0.016	0.010	50092	2.679	3.177
	(30191)	(9465)	(2212)	(495)	(118)	(35)	(16)	(9)	(8)	(5)			
15-20	74.84	33.58	10.74	2.80	0.665	0.127	0.042	0.006	0.006	-	16551	3.446	3.977
	(12387)	(5557)	(1778)	(463)	(110)	(21)	(7)	(1)	(1)				
20-25	82.10	48.06	22.13	7.82	2.301	0.548	0.292	0.073	0.073	0.037	2738	4.274	4.935
	(2248)	(1316)	(606)	(214)	(63)	(15)	(8)	(2)	(2)	(1)			
25-30	85.32	57.95	32.42	14.37	4.128	1.376	0.153	0.153	0.153	0.153	654	4.961	5.749
	(558)	(379)	(212)	(94)	(27)	(9)	(1)	(1)	(1)	(1)			
$\geqslant$ 30	83.33	66.67	40.00	23.33	10.000	6.667	3.333	-	-	-	30	5.592	6.521
	(25)	(20)	(12)	(7)	(3)	(2)	(1)						
All	42.45	11.99	3.19	0.82	0.212	0.063	0.026	0.012	0.008	0.003	212980	2.097	2.654
	(90416)	(25533)	(6786)	(1738)	(452)	(134)	(56)	(25)	(17)	(7)			

(Figures in parentheses are actual numbers of differences exceeding the indicated value).

TABLE 2 - PERCENTAGE FREQUENCIES OF VECTOR DIFFERENCES, $|\Delta V_{AB}|$, EXCEEDING VARIOUS THRESHOLDS (SUMMER MONTHS)

Mean Wind Speed (kt)	Percentages of Vector Differences (knots) exceeding:- 2	4	6	8	10	12	14	16	18	20	Total (N)	Mean (kt)	r.m.s. (kt)
0-5	22.50	4.29	1.16	0.29	0.059	0.040	0.026	0.018	0.004	-	27325	1.402	1.893
	(6147)	(1171)	(316)	(80)	(16)	(11)	(7)	(5)	(1)				
5-10	41.53	9.85	2.45	0.63	0.192	0.072	0.026	0.012	0.006	-	50060	2.049	2.563
	(20789)	(4933)	(1227)	(317)	(96)	(36)	(13)	(6)	(3)				
10-15	62.65	21.35	5.61	1.34	0.346	0.099	0.044	0.028	0.024	0.016	25166	2.804	3.338
	(15767)	(5372)	(1412)	(337)	(87)	(25)	(11)	(7)	(6)	(4)			
15-20	77.18	38.09	13.55	4.11	0.964	0.177	0.059	-	-	-	5083	3.666	4.226
	(3923)	(1936)	(689)	(209)	(49)	(9)	(3)						
20-25	83.51	52.92	27.49	11.34	3.780	1.375	0.687	-	-	-	582	4.602	5.331
	(486)	(308)	(160)	(66)	(22)	(8)	(4)						
25-30	86.64	70.91	47.27	23.64	9.091	1.818	-	-	-	-	55	5.692	6.425
	(46)	(39)	(26)	(13)	(5)	(1)							
$\geqslant$ 30	-	-	-	-	-	-	-	-	-	-	-	-	-
ALL	43.56	12.71	3.54	0.94	0.254	0.083	0.035	0.017	0.009	0.004	108271	2.139	2.720
	(47158)	(13759)	(3830)	(1022)	(275)	(90)	(38)	(18)	(10)	(4)			

(Figures in parentheses are actual numbers of differences exceeding the indicated value).

TABLE 3 - PERCENTAGE FREQUENCIES OF VECTOR DIFFERENCES, $|\Delta V_{AB}|$, EXCEEDING VARIOUS THRESHOLDS (WINTER MONTHS)

Mean Wind Speed (kt)	Percentages of Vector Differences (knots) exceeding:- 2	4	6	8	10	12	14	16	18	20	Total (N)	Mean (kt)	r.m.s. (kt)
0-5	16.79 (3805)	2.10 (397)	0.34 (68)	0.04 (9)	0.004 (1)	-	-	-	-	-	22665	1.210	1.568
5-10	33.28 (14266)	5.17 (2217)	0.80 (345)	0.14 (58)	0.042 (18)	0.012 (5)	0.007 (3)	0.002 (1)	0.002 (1)	-	42865	1.748	2.123
10-15	57.87 (14424)	16.42 (4093)	3.21 (800)	0.63 (158)	0.124 (31)	0.040 (10)	0.020 (5)	0.008 (2)	0.008 (2)	0.004 (1)	24926	2.553	3.006
15-20	73.81 (8464)	31.57 (3621)	9.50 (1089)	2.21 (254)	0.532 (61)	0.105 (12)	0.035 (4)	0.009 (1)	0.009 (1)	-	11468	3.349	3.862
20-25	81.73 (1762)	46.75 (1008)	20.69 (446)	6.86 (148)	1.902 (41)	0.325 (7)	0.186 (4)	0.093 (2)	0.093 (2)	0.046 (1)	2156	4.185	4.823
25-30	85.48 (512)	56.76 (340)	31.05 (186)	13.52 (81)	3.673 (22)	1.336 (8)	0.167 (1)	0.167 (1)	0.167 (1)	0.167 (1)	599	4.894	5.683
$\geq$ 30	83.33 (25)	66.67 (20)	40.00 (12)	23.33 (7)	10.000 (3)	6.667 (2)	3.333 (1)	-	-	-	30	5.592	6.521
ALL	41.31 (43258)	11.24 (11774)	2.82 (2956)	0.68 (716)	0.168 (177)	0.042 (44)	0.017 (18)	0.007 (7)	0.007 (7)	0.003 (3)	104709	2.054	2.654

(Figures in parentheses are actual numbers of differences exceeding the indicated value).

Table 4 Percentage frequencies of vector differences, $|\Delta V_{Sn}|$, exceeding various thresholds (All year).

S_n (time)	Percentages of Vector differences (knots) exceeding:- 2	4	6	8	10	12	14	16	18	20	Total (N)	Mean (kt)	rms (kt)
1 (½ min)	17.99 (38306)	2.42 (5150)	0.35 (752)	0.07 (144)	0.018 (38)	0.007 (15)	0.003 (6)	0.001 (3)	0.001 (3)	0.0005 (1)	212980	1.191	1.607
2 (1 min)	26.90 (57291)	5.37 (11433)	1.02 (2178)	0.21 (454)	0.046 (97)	0.013 (28)	0.005 (10)	0.002 (4)	0.001 (3)	0.001 (2)	212980	1.494	2.000
3 (1½min)	30.51 (64981)	7.02 (14954)	1.49 (3165)	0.34 (726)	0.078 (166)	0.025 (54)	0.009 (19)	0.004 (9)	0.001 (2)	0.001 (2)	212980	1.631	2.178
4 (2 min)	32.81 (69868)	7.95 (16923)	1.84 (3919)	0.43 (920)	0.107 (227)	0.027 (58)	0.012 (26)	0.004 (9)	0.002 (4)	0.002 (4)	212980	1.716	2.277
5 (2½min)	33.98 (72363)	8.76 (18661)	2.07 (4414)	0.50 (1064)	0.117 (249)	0.033 (70)	0.015 (32)	0.007 (15)	0.004 (9)	0.003 (6)	212980	1.774	2.345
10 (5-min)	38.32 (81618)	10.94 (23305)	2.91 (6194)	0.73 (1555)	0.194 (413)	0.062 (131)	0.027 (57)	0.013 (28)	0.009 (19)	0.006 (13)	212980	1.963	2.545
20 (10min)	43.77 (93218)	13.25 (28226)	3.84 (8181)	1.09 (2322)	0.314 (668)	0.099 (210)	0.044 (93)	0.024 (52)	0.015 (31)	0.008 (16)	212980	2.178	2.768
30 (15min)	47.66 (101500)	15.04 (32034)	4.49 (9553)	1.34 (2843)	0.404 (861)	0.152 (324)	0.064 (137)	0.031 (67)	0.015 (33)	0.009 (19)	212980	2.327	2.925
40 (20min)	50.65 (107874)	16.44 (35019)	5.07 (10805)	1.61 (3433)	0.504 (1074)	0.196 (418)	0.089 (190)	0.041 (87)	0.020 (43)	0.009 (19)	212980	2.441	3.050

LP

TABLE 5. PERCENTAGE FREQUENCIES OF VECTOR ERRORS* EXCEEDING VARIOUS THRESHOLDS (ALL YEAR), AS A FUNCTION OF THE PERCENTAGE (F) OF ALL TOUCH-DOWNS/TAKE-OFFS THAT OCCUR NEAR AN ANEMOMETER

Percentage frequencies of vector error* magnitudes (knots) exceeding :-

F (per cent)	2	4	6	8	10	12	14	16	18	20
0	42.45	11.99	3.19	0.82	0.212	0.063	0.0263	0.0117	0.0080	0.0033
	(1.39)	(1.71)	(2.14)	(2.41)	(2.72)	(2.52)	(2.96)	(2.79)	(8.89)	(3.67)
25	39.47	10.75	2.77	0.70	0.179	0.054	0.0220	0.0099	0.0062	0.0027
	(1.29)	(1.53)	(1.86)	(2.06)	(2.29)	(2.16)	(2.47)	(2.36)	(6.89)	(3.00)
50	36.48	9.51	2.34	0.58	0.145	0.044	0.0176	0.0080	0.0045	0.0021
	(1.20)	(1.35)	(1.57)	(1.71)	(1.86)	(1.76)	(1.98)	(1.90)	(5.00)	(2.33)
75	33.50	8.26	1.92	0.46	0.112	0.035	0.0133	0.0061	0.0027	0.0015
	(1.10)	(1.18)	(1.29)	(1.35)	(1.44)	(1.40)	(1.49)	(1.45)	(3.00)	(1.67)
100	30.51	7.02	1.49	0.34	0.078	0.025	0.0089	0.0042	0.0009	0.0009

Figures in paretheses are (percentage frequency) ÷ (percentage frequency for F=100)

* The vector error is defined as the difference between the 30-second wind passed to the pilot about one minute before touch-down/take-off, and that actually experienced at touch-down/take-off.

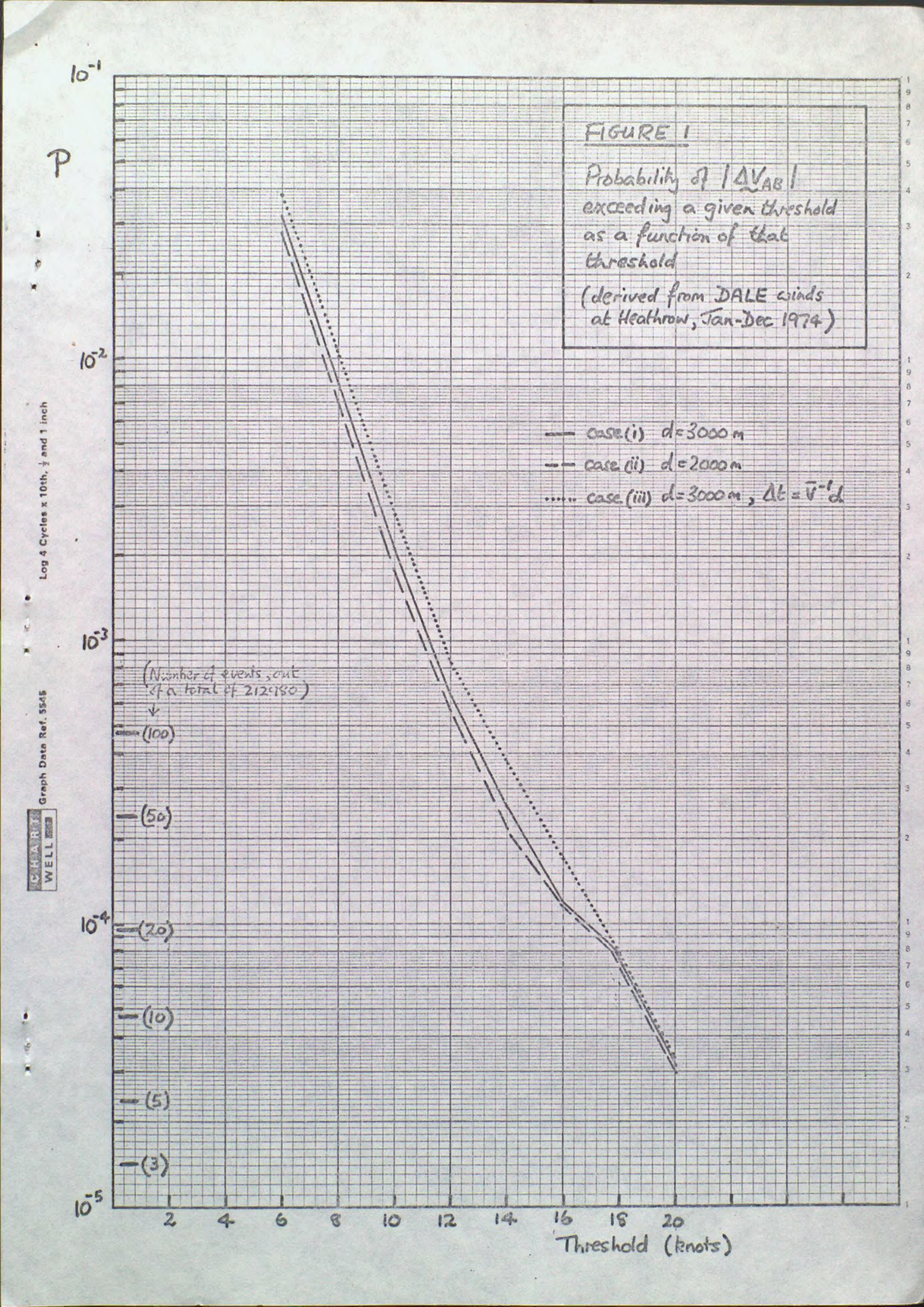
FIGURE 1
Probability of $|\Delta V_{AB}|$ exceeding a given threshold as a function of that threshold
(derived from DALE winds at Heathrow, Jan-Dec 1974)
case (i) d=3000 m
case (ii) d=2000 m
case (iii) d=3000 m, $\Delta t = \bar{v}^{-1} d$
P
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
(Number of events, out of a total of 212,150)
(100)
(50)
(20)
(10)
(5)
(3)
2 4 6 8 10 12 14 16 18 20
Threshold (knots)
Log 4 Cycles x 10th, ½ and 1 inch
CHART WELL Graph Data Ref. 5545

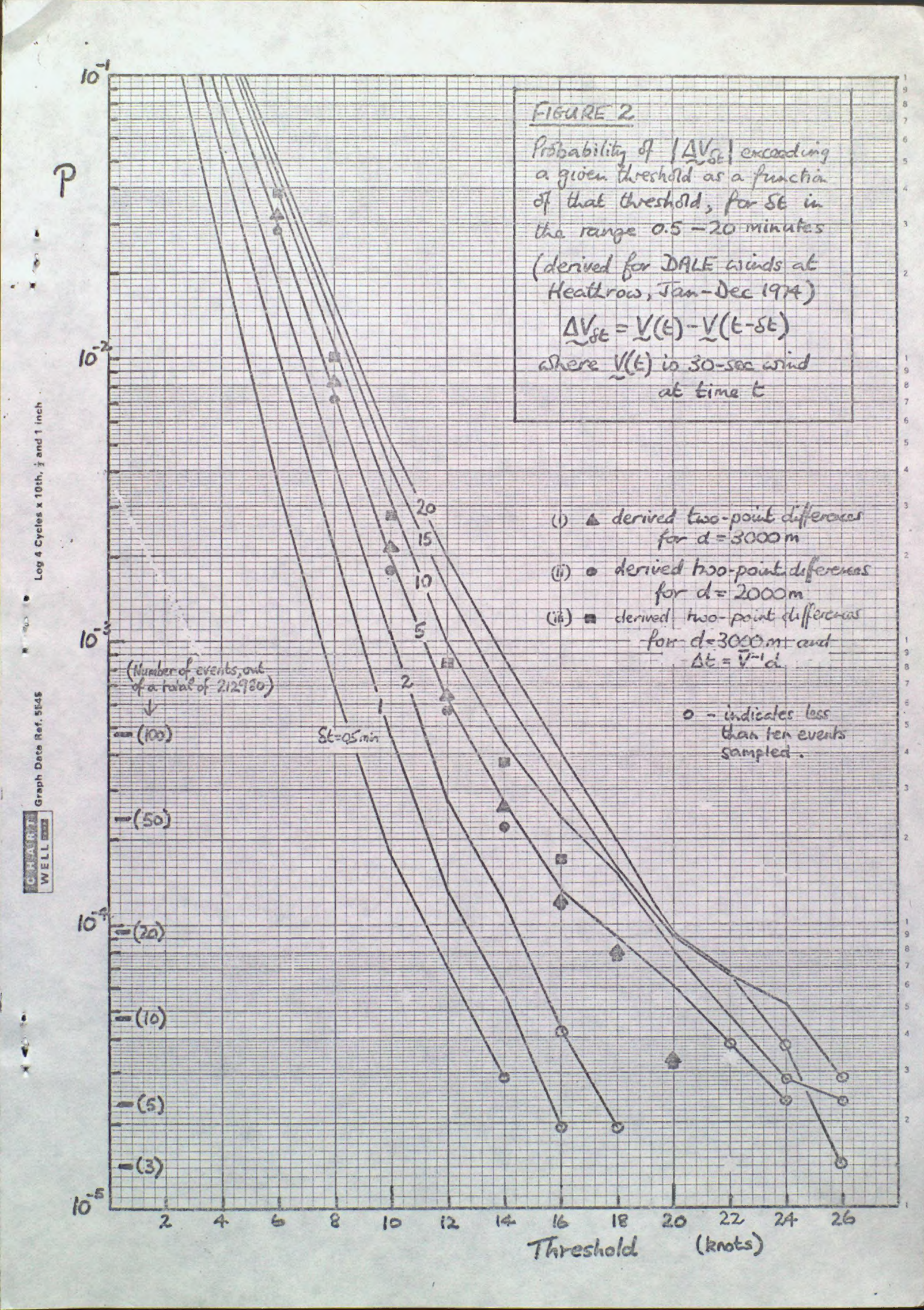
FIGURE 2.
Probability of $|\Delta V_{\delta t}|$ exceeding a given threshold as a function of that threshold, for δt in the range 0.5 – 20 minutes (derived for DALE winds at Heathrow, Jan–Dec 1974)
$\Delta V_{\delta t} = V(t) - V(t-\delta t)$
where $V(t)$ is 30-sec wind at time t
(i) ▲ derived two-point differences for $d = 3000$ m
(ii) ● derived two-point differences for $d = 2000$ m
(iii) ■ derived two-point differences for $d = 3000$ m and $\Delta t = \bar{V}^{-1} d$
o – indicates less than ten events sampled.
P
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
(Number of events, out of a total of 212980)
(100)
(50)
(20)
(10)
(5)
(3)
20
15
10
5
2
1
δt=05 min
2 4 6 8 10 12 14 16 18 20 22 24 26
Threshold (knots)
Log 4 Cycles x 10th, ½ and 1 inch
Graph Data Ref. 5545
CHART WELL

APPENDIX

DALE continuous periods (Heathrow 1974)

Period (times are GMT)

1900	03.01.74 - 1400	07.01.74
2000	07.01.74 - 1000	17.01.74
1100	17.01.74 - 1000	31.01.74
1200	31.01.74 - 1800	06.02.74
2200	06.02.74 - 0600	12.02.74
1100	13.02.74 - 0900	14.02.74
1000	14.02.74 - 0300	21.02.74
1200	28.02.74 - 1600	09.03.74
1400	12.03.74 - 0800	25.03.74
1000	25.03.74 - 0800	01.04.74
2200	01.04.74 - 0900	10.04.74
1300	10.04.74 - 0700	25.04.74
1000	25.04.74 - 1000	07.05.74
1800	07.05.74 - 2000	07.06.74
1100	08.06.74 - 1600	14.06.74
1000	08.07.74 - 1100	23.07.74
1400	23.07.74 - 1400	26.07.74
1500	26.07.74 - 1400	05.08.74
1600	05.08.74 - 0800	13.09.74
1100	13.09.74 - 1800	16.09.74
1300	17.09.74 - 2200	25.09.74
0600	26.09.74 - 1800	12.10.74
0200	13.10.74 - 0900	19.10.74
1300	20.10.74 - 1300	24.10.74
1400	24.10.74 - 1400	03.11.74
1500	03.11.74 - 2200	10.11.74
0900	14.11.74 - 1500	14.11.74
1200	15.11.74 - 0900	18.11.74
0800	19.11.74 - 1100	21.11.74
1700	21.11.74 - 0600	06.12.74
1100	10.12.74 - 0100	13.12.74
0200	13.12.74 - 0000	15.12.74
1700	16.12.74 - 1800	23.12.74
1000	24.12.74 - 2100	26.12.74